SUBSTITUTION AND COMPLEMENTARY EFFECTS OF INFORMATION ON REGIONAL TRAVEL AND LOCATION BEHAVIOR

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ABSTRACT

Current thought on the impact of information technology on society generally argues that it will, among other things, increasingly become a substitute for trip taking. There is also a school that argues that it is also emerging as a compliment to transportation. This paper examines these arguments through a literature review with model development and numerical experimentation. The conclusion is that substitution effects will be sufficient to induce concentration of new growth in U.S. metropolitan regions
far beyond the current "edge city" periphery.

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1.0 Introduction.

The purpose of this paper is to explore the substitution and complementary effects of information on travel behavior and metropolitan spatial form.

One of the last reports produced by the U.S. Office of Technological Assessment before it was terminated in September 1995 was **The Technological Reshaping of Metropolitan America**.[1] This report provides a thorough review and assessment of the technologies that will impact urban and regional form. In particular they focus on the location of employment, location of information-based service industries, location of freight transportation, distribution

[1] Office of Technological Assessment. **The Technological Reshaping of Metropolitan America** OTA-ETI-643 (Washington, D.C.: U.S. Government Printing Office, September 1995).

of manufacturing jobs, and the pattern of transportation and telecommunications infrastructure in metropolitan areas. The general conclusion is that technology is continuing to reduce the friction of distance for the trip to work and for the need for central locations in metropolitan regions. The implication is that the technological forces propelling metropolitan sprawl will intensify and thereby, if left undirected, contribute to the further decline of central cities which is the chief focus of the report's policy recommendations. The report, at best, marginally addresses the policy and management implications for the "cities on the edge" and for the new exurban concentrations that can be expected to develop. The OTA analysis needs to be extended to assess the implications for these outer city concentrations and metropolitan regions as a whole which is the focus of our analysis and modeling.

2.0 Analysis.

Metropolitan sprawl has long characterized the evolution of the American metropolis. In this part of the paper we argue that technology will contribute to increased sprawl, *ceteris paribus*. The analysis first defines the relevant technologies and then describes how they may contribute to the reshaping of U.S. urban structure into a network of relatively equal urban nodes but of greatly expanded urban regions. Related policy and management issues are examined.

2.1 What are the technologies?

To be sure, technology is not the only factor contributing to metropolitan deconcentration and sprawl. Other factors such as lower land costs on the periphery, extensive highway systems lowering transportation costs to outer city locations, residential preferences of Americans for the "marriage of town and country" living styles and the vision of a Jeffersonian rural lifestyle, deteriorating conditions in central cities and finally a set of government policies that provides subsidies ranging from tax policies to depreciation allowances to implicit subsidies in the form of building regulations and policies that discourage efforts to reuse older urban and suburban land have traditionally contributed to metropolitan decentralization.[2] This is to say nothing of the social issues of race and poverty related to segregated spatial patterns. Yet the rapid development and ever quickening deployment of new core technology in the form of computer and information technologies (IT) are making a continuously changing and ever more spatially dispersed metropolitan economy not only possible but a reality. By buttressing communication systems with computer technology a wide variety of electronic communication networks have been developed including local area networks (e.g., to link workers together in an office), wide area networks (e.g., to link the workforce of a large organization across multiple locations and/or multiple organizations) and the Internet which potentially could one day link all people and all organizations together in a global communication network.

Networks make it possible to substitute communication for trips and face to face meetings through telework, telecommuting, and telepurchasing, telemarketing and telemedicine technology systems. Electronic networks and communication systems also make it possible to

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2 *Ibid*, p. 195.

adopt practices like just-in-time inventory, continuous adjustment routing and advanced logistical systems. Information technology applied to vehicles and transportation infrastructure (Intelligent Transportation Systems-ITS) make it possible to increase the productivity of traditional transportation infrastructure by, for example, increasing the capacity of roads and thus reducing congestion and increasing mobility. However it would be foolish to think of communication and transportation as pure substitutes; rather they are complements making each other increasingly efficient in an ever quickening interactive society. Taken together this new emerging set of technology systems is and will continue restructuring metropolitan America. It is increasing the ability of individuals and firms to locate far beyond the metro area as we know it even today.

2.2 Reshaping metropolitan America.

The clarity of the core dominated theory of the city was fading as early as the mid-20th century when complementary centers began to emerge at suburban transportation nodes. By late century these centers as well as new ones further to the periphery had become Joel Garreau's Edge Cities,[3] large outer city concentrations of business and retail activity that rivaled or surpassed their historic geographic core cities in scale, job generation and range of functions.[4] These new competitive "cities on the edge" differed in ways other than just location, e.g., they had "shadow governments" unlike the elected official headed government institutions of traditional cities. In short, metropolitan space is today defined by multiple commercial centers with one or more having greater attraction than the geographic core. These metropolitan regions, unlike the more vertically and linearly structured core dominated urban regions of the past, may be described as a network of centers, with the core city serving as an important but not dominant node among a system of nodes.[5] While the OTA report recognizes this emerging network, it fails to examine the myriad of issues that are implied, choosing instead to focus the policy emphasis on addressing problems of metropolitan core cities. To be sure this is an important issue. However, it is not the only one. Here the focus is on metropolitan structure as a whole and on the array of nodes in the region including inner and outer edge cities, new edge

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[3] See Garreau, Joel. **Edge Cities: Life on the New Urban Frontier**, Doubleday, 1991.

[4] Stough, Roger R., Kingsley E. Haynes, Harrison S. Campbell, Jr., "Small Business Entrepreneurship in the High Technology Services Sector: An Assessment for the Edge Cities of the U.S. National Capital Region," *Small Business Economics,* forthcoming 1996

[5] Brian Berry in his classic paper on "Cities as Systems Within Systems of Cities" **Papers in Regional Science** (1964) first presented this concept in an hierarchical framework but Kingsley Haynes, to my knowledge, was the first to use the network metaphor to describe a system of equally important but specialized nodes in a flatter hierarchy for a framework of the new American Metropolis.

cities beyond the periphery of today's metropolis and satellite cities far beyond the existing development fringe.

2.3 Policy issues of the networked metropolitan region.

First, policy at the broad level of scale must be considered in terms of the network; not just in terms of one (e.g., the core) or several of the network's nodes. Second, nodes will play different yet potentially regionally complementary roles and the relative importance of specific nodes may vary over time, e.g., the geographic core was dominant at an earlier time; satellite cities may be the dominant growth centers of the next decade as edge cities were over the past two decades. Third, the technology systems that are unfolding are forces that will continue to propel metropolitan sprawl and as these systems continue to evolve and become more widely adopted they will intensify the sprawl effect. Other things such as current land use and zoning practices at the local jurisdiction level remaining as they are today, sprawl will be the continuing paradigm of metropolitan development.

Assuming for the moment that land use and zoning practice remain unchanged and that sprawl continues, one should ask: What form it will take? Unlike in the past the new technology systems make possible a potential leapfrogging of development centers over the urban fringe to the intermediate and far periphery. Thus, development may follow a spatial leapfrogging pattern with significant growth occurring in existing (satellite) centers as much as 50-75 miles out from the urban fringe. These distant exurban concentrations, while often relatively small (10,000 to 20,000 inhabitants) frequently have significant land and physical infrastructures including good transportation connectivity with other closer in regional centers. Because of this infrastructure and because of the locational freeing effect the new technologies are having it is likely that these exurban centers will become the primary growth nodes of metropolitan areas over the next decade or two. To the extent there is demand for additional clusters of commercial activity (and there will be in faster growing regions) one can also expect the development of new edge cities in the zone between the current fringe of development and the satellite centers. If one concludes that the new technology makes this leapfrogging sprawl scenario probable, "what are some of the implications for all of the nodes in the expanding metropolitan network?"

First, existing edge cities will, along with the core, join the older nodes in the metropolitan system and thus will be faced with considerable competition from the satellite and new edge cities that have job and business growth and expansion, and probably a high quality of life for those seeking a better balance between "town and country" preferences. Existing edge cities like the core will need to become far more innovative and competitive to hold the jobs and firms that form their economic base because the new nodes will have a relative advantage much as today's edge cities have over the core. Existing nodes will increasingly need to create organized economic development and program initiatives. However, edge cities, at best, have limited institutional infrastructure to carry on these types of activities in a sustained manner given the "shadow" status of their governance. To be sure, edge cities have been able to successfully undertake and deliver uni-functional services such as security and police and beautification. However, there are few, if any, edge cities that have economic development programs that go much beyond real estate development initiatives although some have created non-government organizations to address issues effecting their sustainability such as transportation connectivity and access, e.g., Tytran of Tysons Corner outside of Washington, D.C. Developing and sustaining economic development initiatives while today's edge cities are relative competitive will be a major requirement for survival over the next decade. Further, there is not apt to be much in the way of federal or even state aid to assist in this survival effort although local economic development programs may be worthwhile allies.

The vision of a greatly expanded metropolitan network of satellite and new edge cities has significant implications for transportation infrastructure investments. Most of the metropolitan networks have been developed on the basis of a core dominated metropolitan vision. Thus, metropolitan transportation systems are heavily oriented toward a hub (core) and spoke model. Changes in the last half of the 20th century (especially over the last 20 years) have changed the pattern as today the primary demand for metropolitan transportation is for supporting trips across the system (to link edge cities to one another) rather than to and from the core. The 1990 census showed over and over that commuting patterns were changing from core dominated to network oriented. Connecting this line of argument up with the vision of the networked metropolitan region of the future suggests that transportation infrastructure will need to increasingly connect a network of nodes that is intensifying within the existing metropolitan region while at the same time linking in new edge cities and satellite nodes at greatly expanded distances. Demand for transportation of this nature cannot be satisfied with increased heavy rail and transit which is the solution that many see for the geographic core of the metropolitan area. Nor can it be satisfied with Transportation Demand Measures (TDM). Significant new investment in road and light rail infrastructure will be required, which is the only remotely affordable way to address the growing demand for transportation among the expanded metropolitan network of the future.

Specialized nodes of shopping, arts, business services, manufacturing, and R&D are likely to develop in their own right as are centers with unique historical, architectural or urban artifact elements. Obviously some of the latter will be and are being obliterated but some will survive and become gems of desirability and preservation in this system of urban nodes that will make up the new metropolitan organization.

2.4 Managing sprawl and the expanding metropolis.

The dominant proposal for managing sprawl in the U.S. is to adopt measures that will force greater intensity of development within existing metropolitan clusters and intensify infilling. While the OTA policy proposals seem for the most part to subscribe to this perspective the results of the analysis, as summarized above, show that technology is and will continue driving decentralization tendencies. Further, given the diversity of forces propelling sprawl, the "political will" to counter sprawl does not seem to exist although there are some experiments in early stages of development, e.g., the states of Oregon and Washington. There the state has adopted growth control legislation that permits a metropolitan area to first establish boundaries within which growth will be confined and targeted. For example, Portland, Oregon, has identified twenty some centers that are to receive new growth in the region. The problem with this is that technology is likely to make a number of locations beyond (perhaps even far beyond) attractive for commuters and businesses tied to the Portland regional economy. In short, it is difficult to see how growth can be confined to a "socially" or "politically" defined area when the cost and benefit attributes of places outside this area have relative advantages for at least some people and some businesses.

So what is to prevent the development of broad, decentralized development sprawling out as far as 50-75 miles from the centers of metropolitan areas.

First, at least some will not find this an offensive vision provided that the necessary transportation infrastructure is in place to ensure reasonable cross region access and mobility. To some extent is this not the Randstad of the Netherlands with its multiple nodes and relatively super connective infrastructure, but the suggestion here is that this will be on a North American scale.

Second, with the Oregon or Washington land use provisions it will be necessary to greatly expand the development boundaries to encompass the development frame. Obtaining agreement from the outlying satellite cities and county governments to this end and, therefore, giving up local control over economic development and development decisions will be beyond the institutional capacity of most regions even with the help of state growth control statutes.

Third, a grand metropolitan wide government might be established to manage the region. This is unlikely given that the few metropolitan government experiments have been limited to no more than the core county of the region, e.g., Indianapolis or Nashville. Further, no metropolitan government experiments have been initiated in the last 20 years.

Finally, cooperative arrangements could be adopted but this seems improbable given that even with state statutory help in Oregon, Portland's attempt at focusing growth seems doomed because the growth boundary will not be nearly extensive enough to accommodate satellite city development that appears to be inevitable as technology continues to make decentralization ever more attractive. This is the same problem that the Netherlands has experienced in its continuing difficulty in developing an appropriately decentralized management structure for the nodal interactions of the Randstad and its peripheral regions. This is in the context of a 100 year development rather than the more rapid and chaotic development we have seen in North America. Perhaps the most that can be hoped for in the near future is that some of the outer region counties where new centers are formed will adopt provisions to set aside some land for uses other than development.

3. Modeling.

Starting from the above analysis, we present hereafter two models relating to the phenomenon addressed: one is a model of (household) residential choice, the other a model of (peri)urban development resulting from such choices.[6]

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[6] For a previous approach along the same lines, one is referred to Jean H.P. Paelinck, 1983, *Formal Spatial Economic Analysis*, Gower, Aldershot, chapter 4.

3.1 Model 1: residential choice.

Assume a well-behaved utility function with as arguments a general good, q, three possible residential choices (central city, x_1, suburbs, x_2, edge cities, x_3) and leisure, l :

$$u\,(\,q;\,x_1,\,x_2,\,x_3;\,l\,) \qquad (1)$$

The constraints for the maximizing process are the following :

		(Dual variables)
$pq + p_1x_1 + p_2x_2 + p_3x_3 + \pi l = r^*$	(2)	λ
$tq + t_1x_1 + t_2x_2 + t_3x_3 + \tau l + t^*$	(3)	μ
$x_1 + x_2 + x_3 = 1$	(4)	ρ
$x_i = x_i^2$, I = 1,2,3	(5)	σ_i

(2) is the budget constraint, (3) the time constraint, (4) the residential exclusivity constraint, and (5) the binary constraint.

Consider now the first order condition for x_3; it can be written as :

$$x_3 = \tfrac{1}{2} + (\,u'_3 - \lambda p_3 - \mu t_3 - \rho\,)\,/\,2\sigma_3 \quad (6)$$

where x_3 should be either 0 or 1 (σ_3 guarantees that). One supposes u'_3 to be much larger than u'_2 or u'_1, and further a sudden drop in p_3 (which includes also transportation and discounted moving costs) and t_3, due to "cyberspacing"; in such a case $x_3 = 1$ could supersede x_1 and x_2 as non-zero candidates.

The following example shows this.

Let the utility function be :

$$u = q + 2x_1 + 2.5x_2 + 4x_3 + l \qquad (7)$$

and the prices and unit time requirements

$$p=1,\ p_1=1,\ p_2=2,\ p_3=5 \text{ or } 3,\ \pi=3 \qquad (8)$$

$$t=2,\ t_1=1,\ t_2=2,\ t_3=5 \text{ or } 3,\ \tau=1 \qquad (9)$$

Table 1 hereafter synthesizes the results of the optimization process:

Table 1.[7]

	u	λ	μ	ρ	σ_1	σ_3
$x_1=1$	9.2					
$x_2=1$	8.9					
$x_3=1$ with $p_3=t_3=5$	9.0					3.5
$x_3=1$ with $p_3=t_3=5$	9.6					-7.0
			.6	.2	.9	.3

So in the pre-cyber phase x_1 is the optimal residential choice; it becomes x_3 with the reduction in p_3 and t_3.

3. 2 Model 2: resulting urban development.

This development has been modeled taking into account the previous result and introducing the following explicit assumptions:

A_1 : there are three groups of workers, non-qualified (a), qualified (b) and potential "cybermen" (c); their increase is proportional to total increase in urban active population, with coefficients α_a, α_b and α_c totaling one.

A_2 : activity (in terms of employment) is attracted to the urban area as a function of the presence of b- and c-workers, with coefficient β.

A_3 : a-workers locate in the central city (zone 1).

A_4 : b-workers locate in the central city below a critical density, then move out to the suburbs (zone 2; coefficient γ).

[7] In fact, one of the type-(5) equations is superfluous, as two of them, together with (4), guarantee remaining binarity.

A_5 : c-workers locate in the central city below a still lower critical density (coefficient δ), then move out to the suburbs (fraction ε) and the edge cities (zone 3; fraction 1-ε); if already in the suburbs they move out above a critical density to the edge cities (coefficient ζ).

A_6 : activities locate in the central city as a function of available b- and c-workers (coefficient θ), otherwise in the edge cities.

A_7 : activities are further attracted in zones 1 and 3 above a certain threshold level, and moreover they cross-influence each other (coefficients κ and ν).
The resulting model presents itself as follows, dots above variables symbolizing time differentials; P = (active) population, Q = activities.

$$\begin{array}{l}\dot{P}_{a1}\\ \dot{P}_{b1}\\ \dot{P}_{c1}\\ \dot{P}_{b2}\\ \dot{P}_{c2}\\ \dot{P}_{c3}\\ \dot{Q}_{1}\\ \dot{Q}_{3}\end{array} = \begin{array}{cccccccc} & \alpha_a\beta & \alpha_a\beta & \alpha_a\beta & \alpha_a\beta & \alpha_a\beta & 0 & 0\\ -\gamma & -\gamma & -\gamma & 0 & 0 & 0 & 0 & 0\\ -\delta & -\delta & -\delta & 0 & 0 & 0 & 0 & 0\\ \gamma & \gamma+\alpha_b\beta & \gamma+\alpha_b\beta & \alpha_b\beta & \alpha_b\beta & \alpha_b\beta & 0 & 0\\ \varepsilon\delta & \varepsilon\delta & \varepsilon\delta & -\zeta & -\zeta & 0 & 0 & 0\\ \delta(1-\varepsilon) & \delta(1-\varepsilon)+\alpha_c\beta & \delta(1-\varepsilon)+\alpha_c\beta & \zeta+\alpha_c\beta & \zeta+\alpha_c\beta & \alpha_c\beta & 0 & 0\\ 0 & \theta & \theta & 0 & 0 & 0 & \kappa & -\nu\\ 0 & \beta-\theta & \beta-\theta & \beta & \beta & \beta & -\kappa & \nu\end{array} \begin{array}{l}P_{a1}\\ P_{b1}\\ P_{c1}\\ P_{b2}\\ P_{c2}\\ P_{c3}\\ Q_{1}\\ Q_{3}\end{array} + \begin{array}{l}0\\ \gamma\pi_1^{*}\\ \delta\pi_1^{**}\\ -\gamma\pi_1^{*}\\ \zeta\pi_2^{**}-\delta\varepsilon\pi_1^{**}\\ -[\delta(1-\varepsilon)\pi_1^{**}+\zeta\pi_2^{**}]\\ -\kappa Q_1^{*}+\nu Q_3^{*}\\ \kappa Q_1^{*}-\nu Q_3^{*}\end{array}$$

This can be condensed as system :

$$\dot{\mathbf{y}} = \mathbf{A}\,\mathbf{y} + \mathbf{a} \qquad (11)$$

Matrix (10)22 has a quasi-triangular structure; the coefficients responsible for possible complex eigenvalues (leading to cyclical behavior of the system) are $\alpha_a\beta$ (location of a-workers in the central city), γ (departure of b-workers from the city center), $\alpha_b\beta$ (location of b-workers in the suburbs), and κ and ν (activity attraction and repulsion).

Next step is to simulate system (10)-(11); Table 2 proposes the following values :

Table 2.

Coefficients	Values
α_a	.1
α_b	.6 or .4
α_c	.3 or .5
β	.01
γ	.1
δ	.1
ε	.1 or .5
ζ	.1
θ	.005 or .002
κ	.001
ν	.001

Table 3 suggests initial values and critical levels.

Table 3.

Variables	Values
P_{a1}	30
P_{b1}	15
P_{c1}	15
P_{b2}	5
P_{c2}	5
P_{c3}	0
Q_1	70
Q_3	0
π_1^*	50
π_1^{**}	30
π_2^*	8
π_2^{**}	4
Q_1^*	80
Q_3^*	0

Matrix **A** and vector **a** from (11) then turn out to be :

$$\mathbf{A} = \begin{matrix} 0 & .001 & .001 & .001 & .001 & .001 & 0 & 0 \\ -.1 & -.1 & -.1 & 0 & 0 & 0 & 0 & 0 \\ -.1 & -.1 & -.1 & 0 & 0 & 0 & 0 & 0 \\ .1 & .106 & .106 & .006 & .006 & .006 & 0 & 0 \end{matrix}$$

.1	.104	.104	.004	.004	.004	0	0
.01	.01	.01	-.1	-.1	0	0	0
.05	.05	.05	-.1	-.1	0	0	0
.09	.093	.093	.103	.103	.003	0	0
.05	.053	.053	.103	.103	.003	0	0 [8]
0	.005	.005	0	0	0	.001	-.001
0	.002	.002	0	0	0	.001	-.001
0	.005	.005	.01	.01	.01	-.001	.001
0	.008	.008	.01	.01	.01	-.001	.001

a' = [0 5 3 -5 { .5 , -.7 } { -3 . 5 , -2 . 3 } - .08 .08]

System (11) will be simulated along those lines.[9]

Figure 1 hereafter presents results of simulating the standard system, i.e. the first row of the alternatives in matrix **A** and vector **a**.[10]

There is perfect consistency between activities, expressed in number of jobs occupied and active population present in the urban-suburban-edge area. Except for this consistency check, the coefficients have never been altered to obtain Figure 1.

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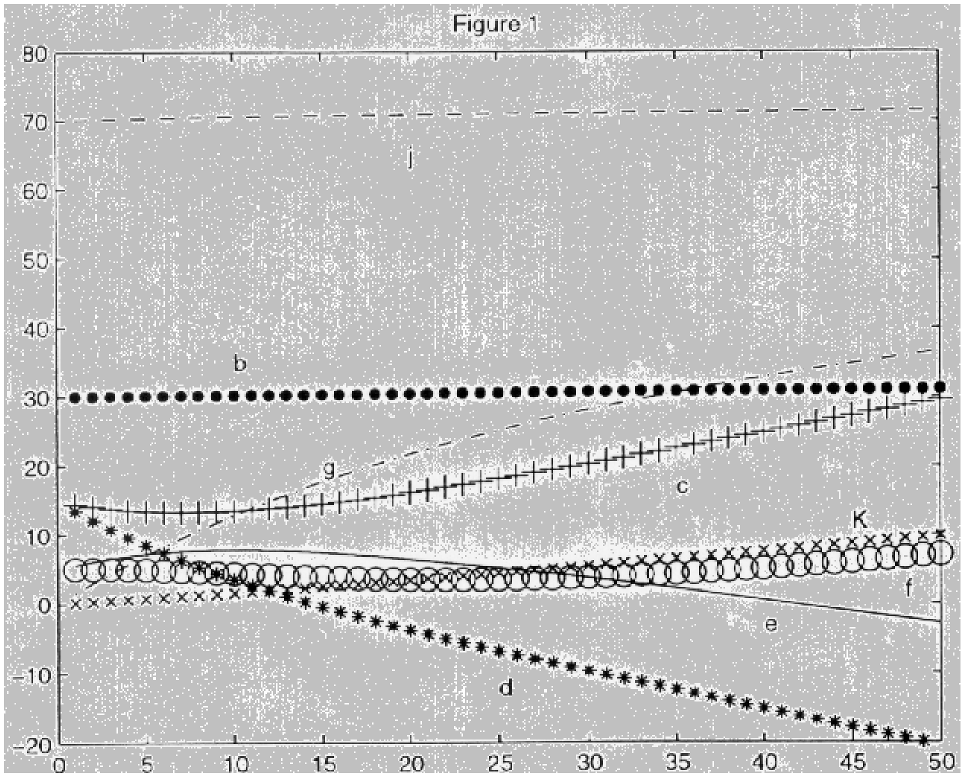
[8] Only combined with $\alpha_c = .3$.

[9] With thanks to Peter Arena and Raj Kulkarni for computational assistance.

[10] The order of the letters corresponds to the order of the endogenous variables in table 3.



It shows :

- a constancy of non-qualified workers and total activity in the city center;

- an increase in qualified workers, and a dramatic decrease of "cyberworkers" in the same central city;

- a stability of "cyberworkers" in the suburbs, and a decrease of qualified workers ("back to the city center"!);

- an increase of "cyberworkers" and of total activity in the edge cities.

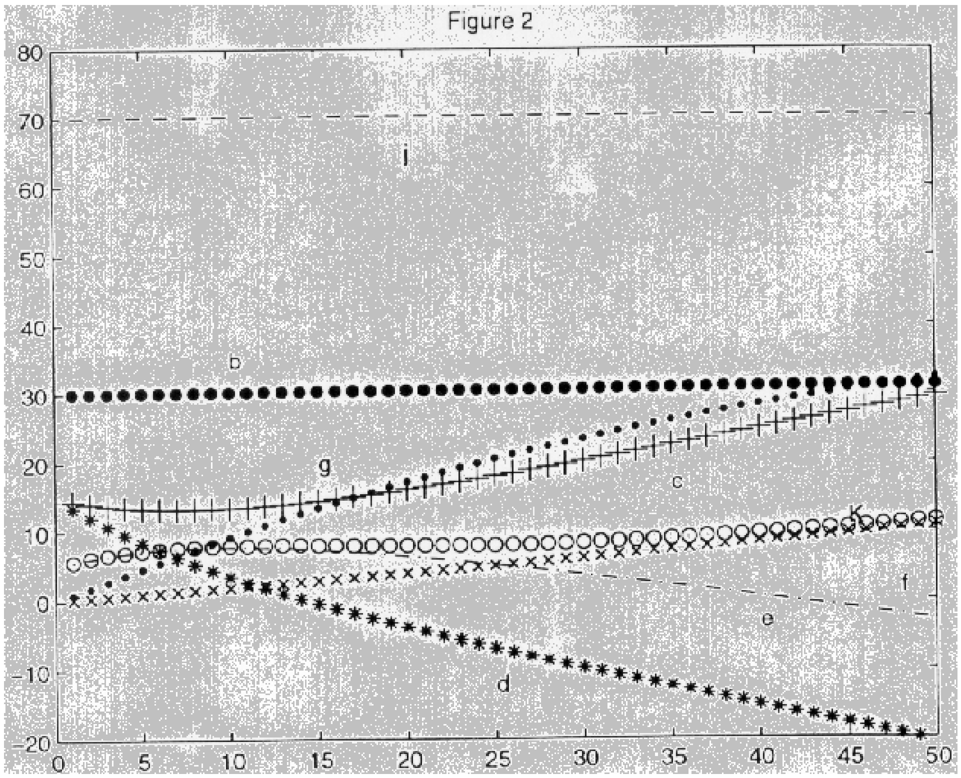
These results match the ones obtained in section 2.

Other simulations have been performed; for instance Figure 2 shows the results of using options

$P_{c2}(2)$, $P_{c3}(2)$, $Q_1(2)$ and $Q_3(2)$, the main substitution observed being P_{c2} vs P_{c3}.

The latter option has also been simulated as a generalized Lotka-Volterra model[11], i.e.

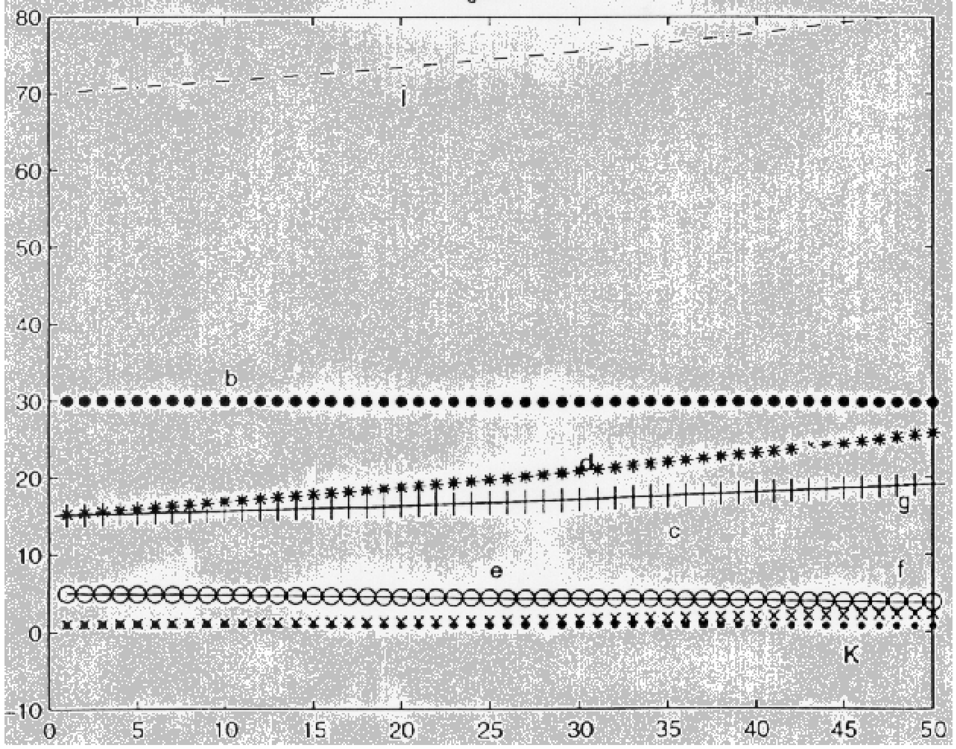
$$\dot{\mathbf{y}} = \hat{\mathbf{y}}\,(\,\mathbf{A}\,\mathbf{y} + \mathbf{a}\,) \qquad \textbf{(12)}$$



Qualitatively the results are similar (Figure 3), except for some “enlarging” and “squeezing”, which is the result of the presence of the multiplicative vector **y**, so the linear version seems to be more adequate in this case.

[11] On generalized Lotka-Volterra specifications, see J.H.P. Paelinck, Contributions récentes après vingt ans d’économétrie spatiale, *Revue européenne des sciences sociales,* Tome XXVII, No 88, pp. 6-10).

Figure 3



4. Conclusions.

This paper develops the hypothesis that urban growth and relocation in the U.S. metropolis will be concentrated in centers far beyond the current “edge city” dominated periphery. While a number of contributing factors are identified, computer integrated communications technology is seen as the newly emerging factor that will induce the hypothesized outcome. While some supporting evidence is cited it is insufficient to fully support the type of decentralization that is described. a residential choice and a related urban development model were developed to examine the hypothesis with numerical analysis. The results support the hypothesis about the future changes in U.S. metropolitan geographic form.

Numerical experiments are similar to simulations and, therefore, are not substitutes for empirical evidence. However, the assumptions upon which the models are erected are quite plausible and, therefore, must be viewed as lending support to the hypothesis or thesis of this paper. Nonetheless, future empirical research is needed to test the hypothesis and the related models.